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NATIONAL SEVERE STORMS PROJECT

REPORT No. 1

National Severe Storms Project Objectives and Basic Design

by

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Kansas City, Mo. and Washington, D. C.

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CONTENTS

		Page
1.	INTRODUCTION	1
2.	OBJECTIVES	3
3.	DISCUSSION OF THE PROBLEM	4
	A. Formation	5
	B. Structure	5
	C. Movement	8
	D. Changes of Intensity	8
	E. Turbulence and Winds	10
	F. Tornadoes	10
4.	DATA COLLECTION	12
5.	RESEARCH OPERATIONS BASE	14
6.	RESEARCH AND DEVELOPMENT	14
	A. Preliminary Analysis Brochure	14
	B. Radar Analyses	15
	C. Photogrammetry	15
	D. Precedent Conditions and Mesoscale Structure	15
	E. Structure of the Low Level Jet Stream	15
	F. Turbulence Analysis	15
7.	PUBLICATION OF RESULTS	15
	REFERENCES	16

NATIONAL SEVERE STORMS PROJECT OBJECTIVES AND BASIC DESIGN

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1. INTRODUCTION

The National Severe Storms Project has been organized as a part of the U. S. Weather Bureau's responsibility in furthering the science of meteorology. Such disasters as the Waco, San Angelo, and Worcester tornadoes in the mid- and latter part of the 1950's, as well as the growing importance of severe weather as a factor in air traffic control, forcefully indicated a need for more basic information concerning severe convective phenomena.

In 1955, the National Severe Local Storms Research Project was established with headquarters in Kansas City adjacent to the Severe Local Storms Forecasting Center.

The primary objective of this project was to conduct such preliminary studies as might assist immediately in improving the accuracy of severe local storm forecasts, and to define the basic research tasks required for a better understanding of the tornado and other severe local storm phenomena. The Project instrumented and operated at first a P-51 and later a P-38 for exploratory flights in the vicinity of and through squall lines and other storms. In 1959, the Project initiated a program of collaboration with the Air Force, Federal Aviation Agency, and National Aeronautics and Space Administration in which multiple plane missions were flown under radar surveillance into a succession of thunderstorms and squall lines in the vicinity of Oklahoma City, base of aircraft operations. A historical résumé of operations and findings of the Project through the 1960 season will be published as Report No. 2 in this preprint series.

Beginning in the spring of 1961 this Project, renamed the National Severe Storms Project, will embark on an all-out effort to obtain the necessary meteorological data to fully describe the squall line and its convective by-products and to test hypotheses concerning its development and movement, drawing upon the results of exploratory flights and conclusions from investigations during the earlier years of the Project. Operating under the sponsorship of the U. S. Weather Bureau with the active collaboration of the National

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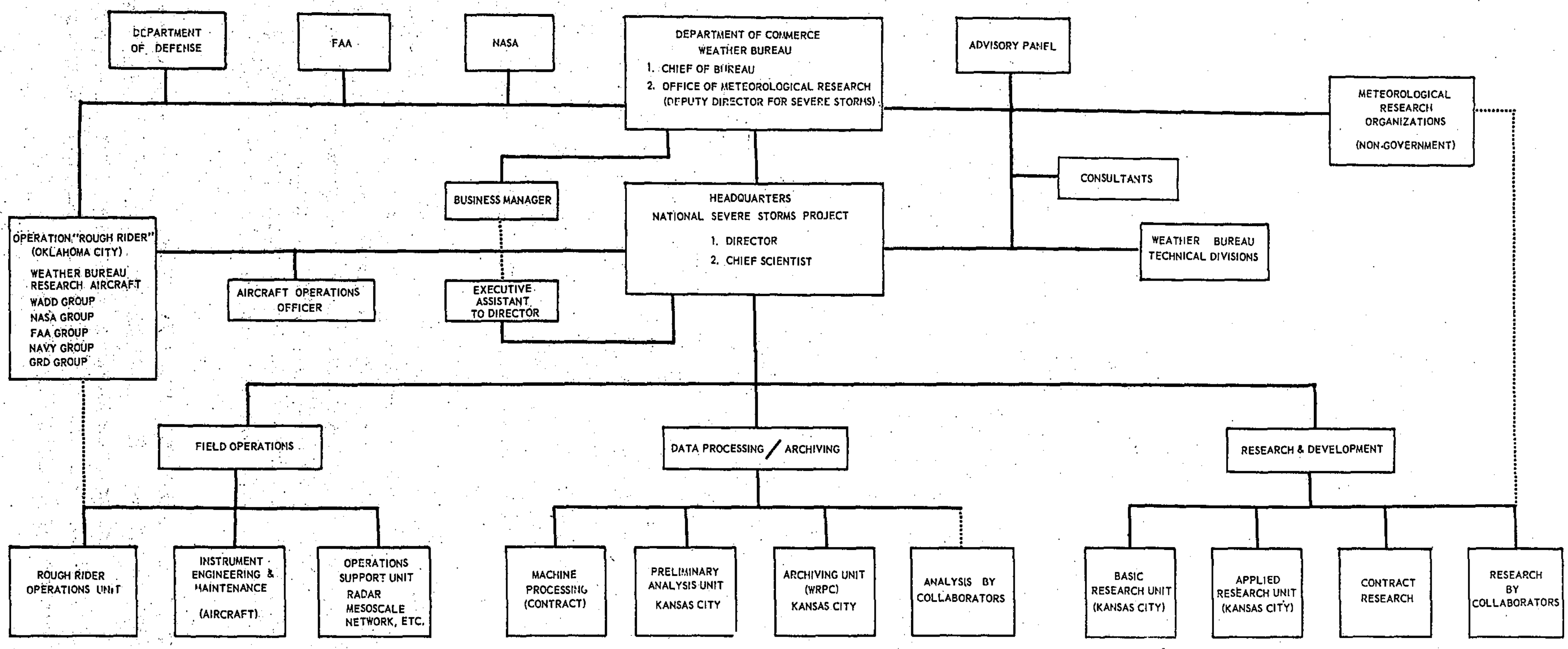
NATIONAL SEVERE STORMS PROJECT

ORGANIZATION CHART



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DATE 12 Dec. 1960

Figure 1. - NSSP organization chart.

Aeronautics and Space Administration (NASA), the Federal Aviation Agency (FAA), the Air Force's Wright Air Development Division (WADD), the Geophysics Research Directorate (GRD), the Tactical Air Command (TAC), and the U. S. Navy, the National Severe Storms Project (NSSP) will undertake one of the largest field research programs ever conceived for the study of a geophysical phenomenon.

Field operations are expected to require approximately six additional years, with year-round research and development activities for a longer period. The organization plan of the Project is outlined in figure 1.

2. OBJECTIVES

The increased scale of operations, although conceived earlier as part of the general plan, has acquired particular urgency due to increased demands of aviation for more exact knowledge of the structure of convective storms, and for more detailed short-period forecasts of the attendant weather phenomena. Initiation of an all-out attack on the severe storms problem at this particular time has been made possible by the development and availability of completely instrumented aircraft capable of probing the storms in three dimensions. The small size, great severity, elusive nature of the by-products, and complex structure of squall line thunderstorms make it necessary to utilize a large number of such aircraft in conjunction with additional observations, if other than piecemeal measurements are to be obtained.

Design of the data collection and aircraft programs is based on recommendations of several conferences held for that purpose, and on experience from both NSSP and the National Hurricane Research Project operations of earlier years. Cloud penetration procedures have been carefully worked out by WADD and radar vectoring from the Weather Bureau's WSR-57 will add an additional parameter to turbulence data. These programs have been designed to permit the testing of a number of working hypotheses concerning squall line inception, movement, development, and dissipation, and will be devoted to collection of information needed to accomplish the following objectives:

1. To investigate the structure and evolution of those parameters of cyclonic-scale disturbances which are responsible for the outbreak of severe convection.

2. To examine and describe the detailed structures of meso- and convective-scale systems so as to understand the mechanisms underlying the growth, movement, and dissipation of squall lines and severe weather cells.

3. To study the distribution and intensity of severe convective by-products (tornadoes, hail, turbulence, lightning, icing, surface gusts) relative to the cloud mass.

4. To develop a qualitative and quantitative classification of convective storms by means of ground-based and air-borne radar.

5. To study the energy budget of severe convective storms.

6. To determine cloud modification methods which may apply to lessening the effects of severe convection.

Objectives have been purposely stated in broad terms, in realization of the fact that not all can be thoroughly investigated during a single season, or perhaps even in several seasons. Particular areas of concentration will in part depend on available observational platforms and the kind of convective situations that develop. The degree to which it is feasible for aircraft to carry out desired objectives is not an unimportant consideration.

It is expected that NSSP will necessarily have to devote virtually all of its attention to the fundamental task of obtaining a clearer understanding of the structure and physical mechanisms of convective storms for the first few years of operation before much effort can be effectively applied to the problems of prediction or possible control. During the course of the research, results made available to the agencies engaged in forecasting severe weather may, however, be expected to be of use in the furtherance of forecasting techniques. Another immediate dividend of this early effort will be information of engineering value to aviation both as regards aircraft design and air traffic control problems.

Research on the severe local storm problem will be carried out mainly by the research staff of NSSP in Kansas City throughout the year, although some aspects of the task will be investigated by research groups elsewhere.

3. DISCUSSION OF THE PROBLEM

In the broadest sense, the objectives of NSSP have a number of things in common with those of the Thunderstorm Project, which yielded a vast amount of information on thunderstorm structure and circulation in its 1946-1948 operations (Byers and Braham, [3,4]).

There are, however, essential differences between the phenomena to be studied by NSSP and those in the area of concentration of the Thunderstorm Project. The field and research operations of NSSP have been designed with these in mind. The principal differences are:

1. The investigation will be concerned fundamentally with the mesoscale setting for a squall line segment in which dimensions and dynamics are of a different order than the smaller "air mass" type thunderstorm.

2. Theoretical and empirical evidence indicates that the squall line type thunderstorm has a high degree of organization, with structures related in a systematic manner to such features as the wind structure of the environment.

3. New instruments have been developed with which to make meteorological measurements. Outstanding among the new observational capabilities of the aircraft is Doppler automatic navigation equipment which will make it possible to map the wind field in and around convective storms, and to study the kinematic properties during all stages of convection.

The following discussion is intended to be descriptive of the general problem of severe convective phenomena:

A. Formation.

Organized convective systems typically form (Showalter and Fulks [14], Fawbush and Miller [5], Fulks [7], U. S. Weather Bureau [16], and House [10]) in conditionally and convectively unstable air where large amounts of water vapor are available in lower levels. The air is usually quite dry aloft, and some hours prior to storm formation there is often a marked stable layer which inhibits penetration of convection into the middle and upper troposphere. Typically, this air mass structure is brought about by differential horizontal advection of heat and moisture at upper and lower levels, and great potential instability may be created in a few hours ahead of a strong cyclone in the proper geographic location.

Release of instability may be brought about partly by organized vertical motions which modify the vertical structure of the atmosphere (Beebe and Bates [1]), and partly by insolational heating.

During the stage precedent to convective outbreaks concentration of effort will therefore be entirely on gathering data useful for studying stability and moisture distributions and their changes with time, and on wind measurements in geographically fixed patterns designed to reveal detailed velocity profiles and to facilitate computation of horizontal divergence and vertical motions.

Special attention will be given to areas known to be favorable to convective outbreaks. Among these is the "dry front" separating low-level maritime tropical air from continental tropical air, where repeated traverses will be made to determine the detailed thermal, moisture, and wind structures and their changes prior to onset of convection.

Continuous photographic reconnaissance over a large area will be carried out for the purpose of determining the regions of first outbreaks and the nature of the convection in the beginning stages. This, of course, will be tied in with radar surveillance and sferics.

B. Structure.

Many studies have indicated that squall line thunderstorms are strongly asymmetrical in structure (Harrison and Orendorff [9], Williams [17], Byers and Braham [3], Tepper [15], Fujita, Newstein, and Tepper [6]). No two squall lines are alike in all respects, and all have extremely complicated and rapidly changing structures. Nevertheless, theoretical and empirical evidence (Newton and Newton [13], House [10], Browning and Ludlam [2]) indicate that there is on the average a high degree of organization. One of the most difficult but potentially most rewarding tasks of the Project will be to distinguish structural features that are conservative from those that are transitory. In order to accomplish this aim, the general plan is, after the reconnaissance of geographically fixed areas in the preconvection stage, to divert most or all aircraft to the area of activity once convection begins.

The typical squall line is made up of a series of large convective clusters, each of which is usually separated from the others by a region of lesser activity. These storms individually last for several hours, although their detailed structures may continually change during that time as their component cells grow and die out.

A simplified sketch of an isolated storm is shown in figure 2, illustrating one of the hypotheses (Newton [12]) upon which the planning has in part been based. Ambient winds are indicated at two levels, say 500 mb. (V_u) and 850 mb. or lower (V_L) for the characteristic situation wherein the wind veers with height. A consequence of mixed updraft and downdraft cells would be to transfer horizontal momentum, and perfect mixing would lead to mean in-cloud motions as indicated by the dashed arrows. Although complete mixing cannot be expected, radar and photographic observations indicate that this effect is present and that the storm, at any given level, moves at a velocity different from that of the environmental winds. A consequence is that, with this type of vertical shear, relative motions are generated between the ambient winds and the in-cloud air, having the general nature indicated in figure 2. The feeding of moist, unstable air into the right flank of the storm in lower levels, accompanied by its removal aloft on that flank, favors the generation of new convection on the right flank. Thus there are suggestions, supported by empirical evidence, that the structure and movement of such a storm are controlled partly by an internal mechanism arising from the wind distribution in the environment.

The decision has been made, whenever the weather situation allows, to concentrate the bulk of reconnaissance on a single storm cluster rather than on the whole of a squall line. This is based partly on the philosophy that the individual storm is the fundamental building block in the squall line structure, and partly on the practical consideration that the squall line *en toto* is too extensive to allow detailed reconnaissance of all storms. Some specific aims in the investigation of structure are:

1. To establish the general features of the rainstorm, with regard to distribution of precipitation of various types, patterns of formation of regenerative convection, and distribution and intensities of gusts and vertical drafts.

2. To establish the typical patterns of surface winds and gusts.

3. To establish to what extent the storm is controlled by stability and other conditions in its environment, and to what extent by internal mechanisms.

4. To determine the geometry and dynamics of inflow and outflow layers and their variation with time, and to relate these to the energy and moisture budgets of the storm.

5. To study the distribution and evolution of tops of cloud towers, and to relate these and radar echoes to the types and intensities of precipitation, and the magnitude of turbulence and vertical drafts.

6. To study the electric field beneath and around rainstorms.

In pursuing the study of structure, coordinated use will be made of RHI and PPI radar and of aircraft, together with surface and aerological

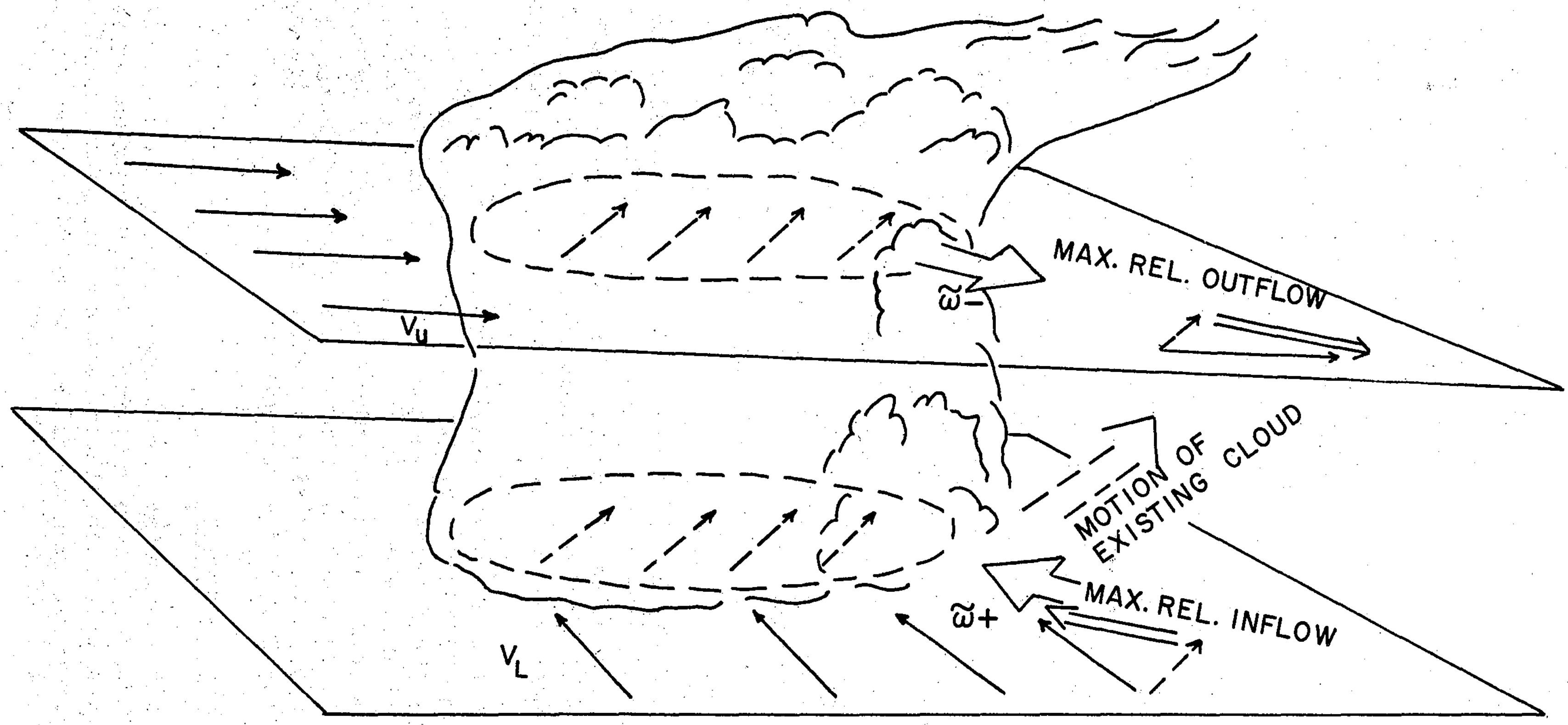

Figure 2. - Showing the ambient winds (upper level, V_u; lower level, V_L), in-cloud winds (dashed), and relative motion of ambient with respect to in-cloud air (double arrows). After Newton [12].

observations. Aircraft will fly several types of patterns around storms at several levels, designed to reveal the wind distribution in the neighborhood of the storm, and the inflow and outflow of momentum, moisture, and heat. Subsonic and supersonic penetrations will be made for turbulence and draft measurements. Photogrammetry and radar will yield information on storm structure at the outside boundaries and within. At the surface, the large-scale characteristics will be studied on the basis of the α-network shown in figure 3. So far as possible, storms will be studied as they move over a special surface network furnished with recording wind equipment, as well as other standard meteorological instrumentation (fig. 4), so that flow patterns and temperature, moisture, and rainfall distribution at the surface can be correlated with measurements aloft.

The β-network shown by the larger grid on figure 4 will be in operation in 1961, and the γ-network shown by the closer grid will be installed for operation during the 1962 season.

The derived benefits from the above objectives will be an increased understanding of the mechanics of convection which will contribute toward solution of general forecasting problems, and information of immediate value in the interpretation of radar and other routinely available observations.

C. Movement.

Studies of the movement of a squall line as a whole, and of its individual storm clusters, are both of interest. The first of these is appropriate to general public forecasts beyond one to three hours, while the latter is most feasible on a very short time scale, and is of great import on that scale (for example, for air traffic control measures including air terminal and landing conditions).

Improved knowledge of synoptic factors (stability and moisture distributions, general flow patterns) governing the large-scale over-all patterns of convection can be expected from the considerable emphasis that will be given to analysis of the complete synoptic situation, in relation to the extensive cloud photography and radar observation and photography programs.

A considerable body of evidence has been accumulated which indicates that the movement of individual storms is influenced both by the general flow pattern and by the internal dynamics of the storm. The partition between internal and external influences will be examined not only in the light of findings on the physical structures of storms, as revealed by the aircraft, but also by a more general examination of movements of radar echoes in relation to their sizes, shapes, and intensities, and in relation to the general flow patterns and stability in their environments.

D. Changes of Intensity.

One of the principal problems in severe storm forecasting is to predict the cessation of intense activity. In the broadest sense, changes in intensity of convective storms should be related to variations of the physical controls in the environment upon which the storms feed; that is, moisture, stability, and wind distribution.

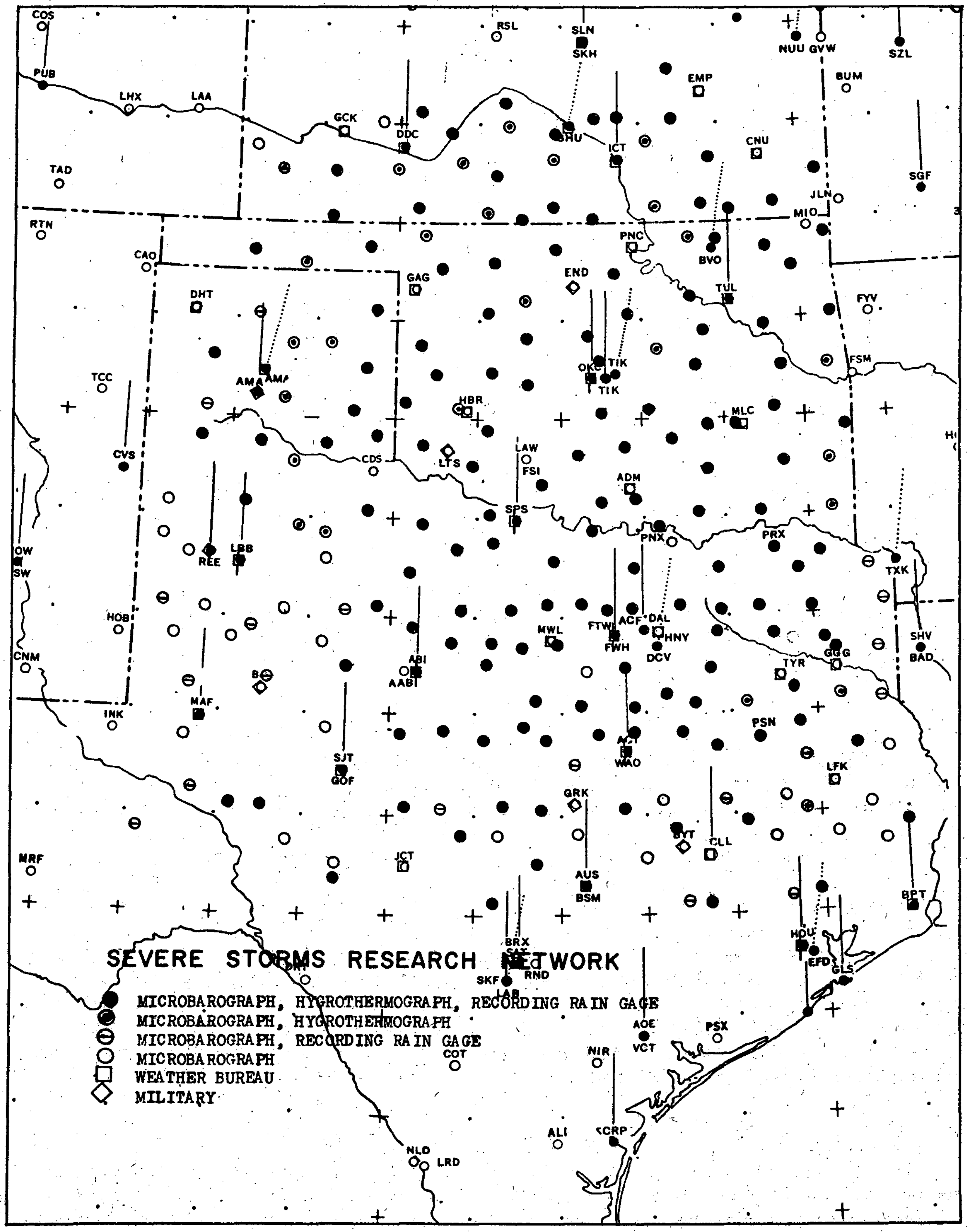

Figure 3. - NSSP surface stations (Alpha network).

The spatial distribution and time variations of these controlling factors is inadequately determined by the sparsely distributed regular aerological soundings taken at 12-hour intervals. One of the principal activities of the Project will be to fill in these space-time gaps, both by use of the aircraft and by use of serial soundings at frequent intervals by both regular and special mobile rawinsonde stations.

E. Turbulence and Winds.

A number of aircraft will be equipped with fast response probes capable of measuring extreme gusts and drafts in both the vertical and horizontal planes. Some of these aircraft will penetrate deep into the convective masses of the squall line segment. Others will measure primarily clear air turbulence and gradients of vertical motion from the environment to the edge of the convective cores. If the number of cloud penetrations is sufficiently large, it should be possible to find systematic distributions of both in-cloud and clear-air turbulence, related to the storm structures discussed in Section B above. Special attention will be paid to the correlation between turbulence and steep radar echo intensity gradients.

There are indications that under conditions of strong vertical shear, large convective clouds act as obstacles which create disturbances in the wind field sufficiently large to be of consequence for navigation of aircraft around storms and through corridors between active squall line segments. This general question, as well as the related question of representativeness of rawin observations as affected by the presence of convection, will be investigated by aircraft mapping of the usual meteorological parameters including the wind field.

The surface wind and gust distribution is also of special interest from the standpoint of ground control of aircraft landings and departures. These features will be studied with use of the special surface network (fig. 4), with an aim to discovering systematic patterns that can be related not only to the three-dimensional structures of storms as revealed by special Project observations, but more generally to radar observations that will always be available without regard to the framework of this special investigation.

F. Tornadoes.

Although several quite different hypotheses have been proposed for tornado formation, no generally accepted theory has yet been developed, and such a theory manifestly has to follow observation. Whenever possible, aircraft will be utilized to make visual and meteorological measurements (including winds and close-in radar scans) in the particular sector of convective storms where tornadoes usually form, especially when radar hooks or other indications of suspected tornadoes are present.

There are reasons to believe (Markgraf [11], Fulks [8]) that the source of rotation for tornadoes lies in the upper levels, in the form of eddies in the lee of clouds that penetrate strong winds aloft. This is one hypothesis that will be investigated by direct measurement of the wind field; aircraft will of course have to stay well clear of the tornadoes themselves.

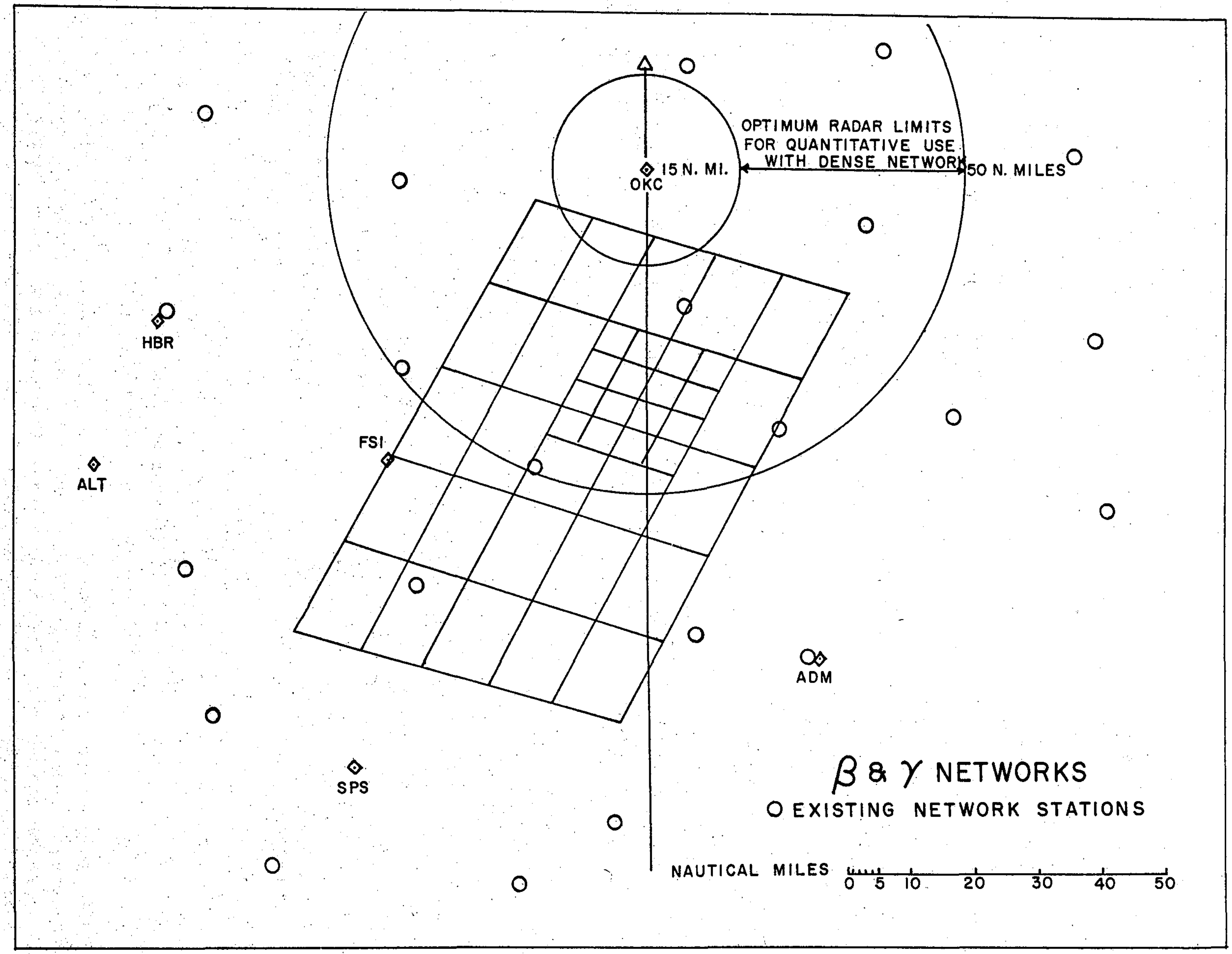

Figure 4. - NSSP surface stations. (Beta network with stations near intersections of large grid will be operative in spring of 1961; Gamma network (small grid) in 1962.)

4. DATA COLLECTION

As discussed earlier, the philosophy to be followed by NSSP in the collection of data on a squall line by aircraft and other facilities is that all available equipment will be devoted to the detailed description of a segment of a developing squall line. Once convective clouds develop in a suspect squall line region, available mobile facilites will be concentrated around that segment of the line which appears most likely to develop into a severe storm and to move directly over the dense surface network of observing stations southwest of Oklahoma City. Figure 4 shows the β network of surface stations supporting the NSSP investigation. Located 15 - 20 miles apart and managed by cooperative observers, each station is equipped with a recording anemometer, microbarograph, hygrothermograph, and weighing rain gage. A few of these will also have electric field meter equipment, and it is planned to provide each station with hail measurement equipment.

Surrounding the supporting β surface network will be a group of rawinsonde stations, most of which are permanent installations. Others are mobile stations which may be moved from one location to another, as required by the seasonal movement northward of severe storms. Serial rawinsondes from most of these stations will be made upon request of NSSP prior to and during the passage of the squall line segment under investigation. Serial rawinsondes normally will be at hourly or one and one-half hourly intervals.

Figure 5 shows a line of pibal observing stations which will operate for a 10-day period in April for the purpose of observing changes and development of the low level jet stream during the 24-hour period in which the squall line develops.

Aircraft supporting the operation will include the following meteorologically instrumented aircraft with suitable recorders:

2 DC-6s (Wea. Bu.)
1 B-57 (Wea. Bu.)
1 B-26 (Wea. Bu.)
1 B-47 (GRD, intermittent)
1 C-130 (GRD, intermittent)
1 A3D (Navy, intermittent)

In addition, the following partially instrumented aircraft will be used in the operation:

1 F-106 (WADD-NASA)
1 B-66 (WADD)
1 B-47 (WADD)
1 U-2 (GRD, intermittent)
1 B-66 (TAC, intermittent)

NSSP plans to use three calibrated radars. One is the WSR-57 at the Weather Bureau Office, Oklahoma City; another is the CPS-9 radar at the Air Weather Service Detachment, Tinker Air Force Base, and the third is the FPS-6 or 10 located at a nearby Air Defense Command site. All these will be carefully calibrated for quantitative measurements. In addition, air traffic

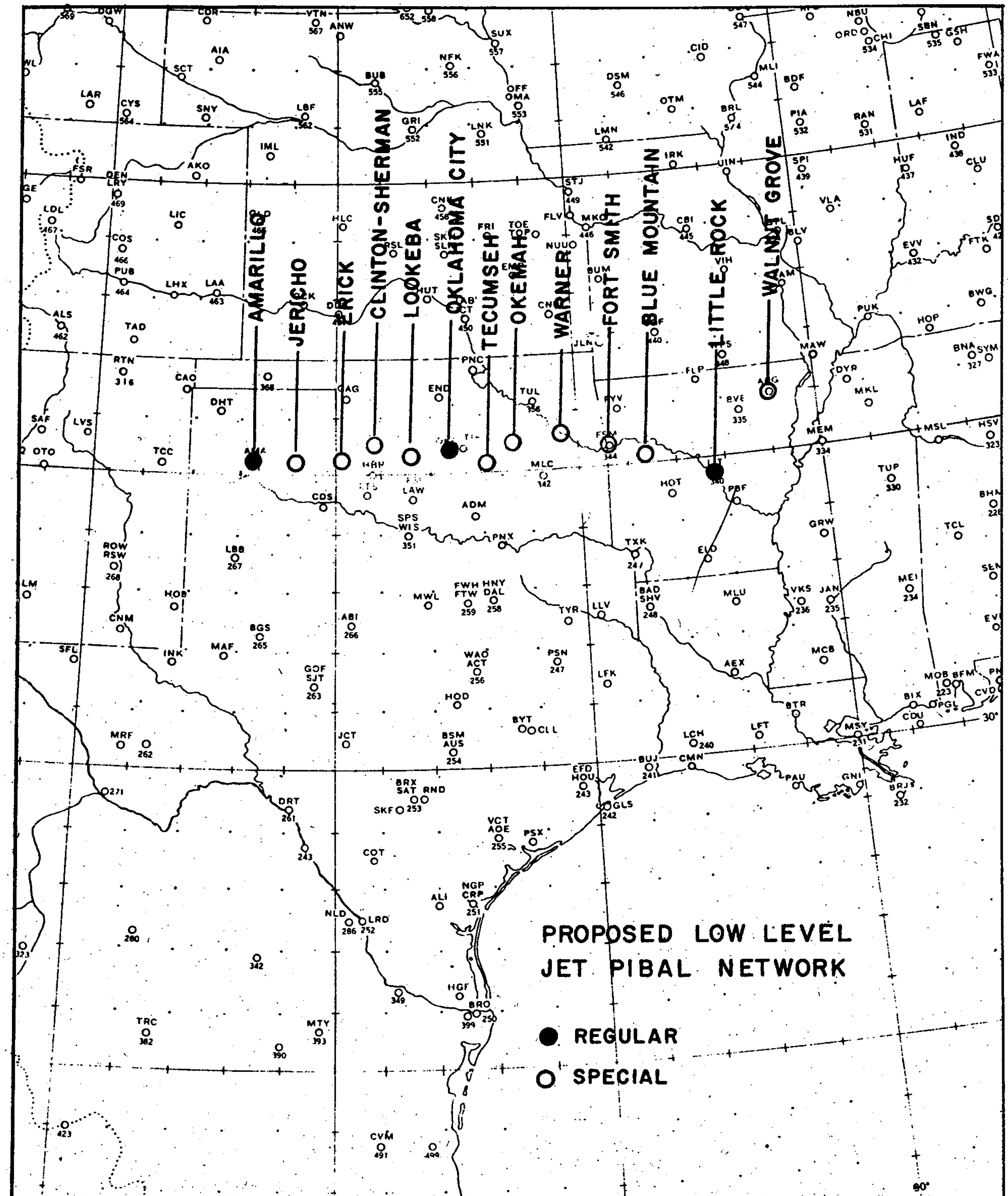

Figure 5. - NSSP pibal stations (Proposed network to measure the low level jet).

control of the project aircraft will be handled from the WSR-57 console onto which the video output of a separate IFF radar (AN/MPX-7) will be superimposed so that all project aircraft equipped with transponders can be identified and located accurately on the PPI scope. NSSP will operate from a remote scope to prevent congestion at the main console.

Other units of the Air Force are involved in separate but cooperative programs in this Project. The GRD will conduct (1) a surface photogrammetry project and (2) a quantitative radar program. The Air Defense Command will (1) conduct a radar scope photography program and (2) cooperate directly in the use of their facilities. The Air Weather Service will make its sferics observations available to NSSP.

The GRD and the U.S.Army Signal Corps are sponsoring a data collection project operated by the University of Texas and Texas A and M. This project consists of an instrumented tower near Dallas, Tex. and a surrounding surface network. Cooperation between this project and NSSP has been assured.

During the latter portion of the operation at Oklahoma City, some of the fully instrumented aircraft will be deployed to Denver for special research flights in connection with hail-producing storms in northeastern Colorado. This operation will be conducted in collaboration with scientists from Colorado State University who operate a special hail collection network in that area.

5. RESEARCH OPERATIONS BASE

As indicated earlier, the base of operations during the spring of each year will be Oklahoma City. A large segment of the permanent project staff at Kansas City will be detached to support the operations in Oklahoma. These personnel, along with those of cooperating agencies (Air Force, FAA, NASA), will work together in planning, dispatching, and operational management of the aircraft facilities supporting the Project, in data quality control, and in preliminary analysis. The period of operation from this base will nominally be March 1 to June 1. Headquarters for the staging will be at Will Rogers Airport in quarters near the present Weather Bureau Airport Station.

6. RESEARCH AND DEVELOPMENT

The general objectives of research have already been discussed. The specific research tasks to be undertaken will represent a collaboration between the permanent staff at Kansas City and research units of the GRD, NASA, WADD, and several university groups. Some of the specific research tasks are:

A. Preliminary Analysis Brochure.

The Kansas City staff will undertake a preliminary analysis of synoptic and mesoscale conditions which were present during the development and movement of the squall line investigated on each day when most of the facilities were employed. This will include the kind of information which will assist a research worker in deciding whether the situation is one in which he might desire to make a detailed study. The brochure will include an index of all data collected during the investigation, its availability, and the form of record.

B. Radar Analyses.

Radar analyses of three kinds will be conducted: first, to describe the segment of the squall line investigated as a basis for compositing aircraft data; other analyses will be concerned with the delineation of vertical motion contours, and still others with the distribution and size of hail, tornadoes, heavy rain, and/or other interesting convective phenomena.

C. Photogrammetry.

Stereophotography will be conducted from ground installations near the Oklahoma City base of operations. These photographs will be analyzed by the GRD participating units. Other photogrammetric analyses, using pictures made from Weather Bureau research aircraft, will be conducted by the analysts at the University of Chicago.

D. Precedent Conditions and Mesoscale Structure.

The Kansas City staff will analyze the conditions of the synoptic and mesoscale structure of the atmosphere precedent to the formation of the squall line with a view to isolating the necessary and sufficient conditions for its formation and maintenance. The staff will also analyze the mesoscale circulations and dynamics of the squall line segment and attempt to isolate the primary energy sources and sinks upon which the segment depends for its development.

E. Structure of the Low Level Jet Stream.

A Weather Bureau Central Office unit will study the structure of the low level jet stream, its modification, and its role in the outbreak of squall line convection.

F. Turbulence Analysis.

The NASA Group at Langley AFB will conduct vertical motion studies to determine the distribution and character of vertical motions in the squall line.

From these several studies will come engineering information of direct importance to aircraft structural design and for application to the use of radar in vectoring aircraft through severe storms, and in addition information of direct benefit to the forecaster in designing for accurate procedures for predicting tornadoes and other forms of severe local storms.

7. PUBLICATION OF RESULTS

It is planned to issue progress reports and, at irregular intervals, the results of special studies growing out of NSSP, as soon as possible after their completion. The more important papers and investigation results will be offered for publication in scientific journals and monograph series which insure very wide circulation. The purpose of the pre-publication series inaugurated with this issue is to serve as a means of disseminating information to specially interested persons, more rapidly or in more detail than might be possible via the regular publications.

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